We demonstrate topological defect lasers in a GaAs membrane with embedded InAs quantum dots. By introducing the disclination to a square-lattice of elliptical air holes, we obtain spatially confined optical resonances with high quality factor. Such resonances support powerflow vortices, and lase upon optical excitation of quantum dots, embedded in the structure. The spatially inhomogeneous variation of the unit cell orientation adds another dimension to the control of lasing modes, enabling creation of desired field pattern and energy flow landscape.

The topological defect laser was fabricated in a 190nm-thick free-standing GaAs membrane, by means of electron-beam lithography and subsequent etching steps. As shown in Fig. 1, the 32x32 elliptical air holes were distributed on a square lattice with an angular orientation of $\Phi = \theta + c$, with $\theta$ being the polar angle of the ellipse on the square grid and the topological charge $c=\pi/4$. The ellipticity of the air holes is $\epsilon = 1.4$. In order to increase light confinement in the structure, a 4x4 void was introduced in the center of the pattern. InAs QDs were embedded in the membrane to supply gain for lasing upon optical excitation.

We observed lasing in the localized mode of the structure shown in Fig. 1. When the lattice constant was changed from 200 to 220 nm, a different mode was tuned into the QD gain spectrum and started lasing.

To understand the nature of the lasing modes in the topological defect structure, we performed 3D numerical simulation. In comparison to the defect state in a regular photonic crystal (square lattice of circular air holes), the field profile of a localized state in the topological defect structure is notably modified. As shown in Fig. 2, an optical vortex occurred in the center of the structure. The observed vortices are attributed to a symmetry breaking between the coupling of the clockwise and counterclockwise traveling waves in the central defect region to the extended states in the surrounding structure.

Figure 1: (a) Electron microscopic image of a topological defect laser

Figure 2: Spatial field distribution of a localized mode in the the topological defect structure (a) and in the PhC crystal with circular holes (b). (c,d) Corresponding optical power flow of the two modes in (a,b), respectively.